
AIRPORT COOPERATIVE RESEARCH PROGRAM

Research Results Digest 10

Light Detection and Ranging (LIDAR) Deployment for Airport Obstruction Surveys

DETAILS

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LIGHT DETECTION AND RANGING (LIDAR) DEPLOYMENT FOR AIRPORT OBSTRUCTIONS SURVEYS

This digest presents the results of ACRP Project 3-01, "Light Detection and Ranging (LIDAR) Deployment for Airport Obstructions Surveys." The study was conducted by a research team under the leadership of the University of Mississippi. The Principal Investigator was Dr. Waheed Uddin.

SUMMARY

Airports conduct obstruction surveys to identify obstacles—for example, towers, buildings, trees—that may pose hazards to air navigation in the vicinity of an airport. The surveys, which must conform to requirements established by the federal government, have traditionally been conducted using aerial photogrammetric and ground-based survey methods. Rapid development of LIDAR (light detection and ranging) technology in recent years is thought by many people to offer a cost-effective alternative to the traditional methods for collecting the data required to prepare airport obstruction surveys meeting government requirements. This digest describes research conducted to investigate the readiness of LIDAR technology for this application. A product of the research is a sample specification that responsible agencies might use to procure LIDAR-based aerial survey services to produce an airport obstruction survey.

This digest is organized into three sections and an appendix. The initial introduction section describes the context for airport obstructions surveys and Federal Aviation Administration (FAA) standards for those surveys. The second section reviews the state of practice with respect to applications of airborne LIDAR technology, particularly for airport obstruction surveys. The final section discusses the sample procurement specification developed by the research team to facilitate design of a LIDAR-based survey. The sample procurement specification is presented in an appendix.

INTRODUCTION

Airport obstruction surveys are used by airports to determine when action is needed to avoid or remediate impingements on airspace (for example, trimming to reduce the height of trees near runways); by airlines to analyze flight paths for their aircraft; and by the FAA to analyze and design controlled airspace features such as new instrument approaches, including global positioning system (GPS) approaches. Airports also use these surveys to update Airport Layout Plan (ALP) drawings that may become the basis for restricting the heights of structures that could impinge on airspace and to note locations of temporary potential obstructions such as construction cranes.

The National Oceanic and Atmospheric Administration's (NOAA) National Geodetic Survey, operating under a series of interagency agreements with the FAA, is responsible for certifying that information developed from obstructions surveys meets the requirements for operation of the

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National Airspace System. Within the airspace surrounding each airport, *obstruction identification surfaces* provide the basis for determining whether or not a topographic feature constitutes an obstruction. Towers, trees, buildings, or other features whose location and height are calculated to penetrate the obstruction surface qualify as obstructions that may pose hazards to air navigation. The characteristics of these imaginary surfaces are established by the Code of Federal Regulations Title 14 Part 77, "Objects Affecting Navigable Airspace" (CFR 14 Part 77) and related FAA guidance on airport airspace analysis.

Most obstructions-survey data are obtained using traditional field-survey and photogrammetric methods. A NOAA-certified obstruction survey using such traditional methods takes approximately 6 months and can be costly. A backlog of demand for such surveys typically exceeds the funding available under federal programs, so that some airports may operate with obsolete and possibly inaccurate obstructions information. In addition, introduction of new GPS approaches at some airports has increased demand for new obstructions surveys. Seeking to reduce costs and enhance accuracy of obstructions surveys, FAA and NOAA have sponsored research on the use of airborne LIDAR technology. This research has shown promise that airborne LIDAR data can be used effectively in analysis and accurate mapping of obstructions.

ACRP Project 03-01 "Light Detection and Ranging (LIDAR) Deployment for Airport Obstructions Surveys" was begun in January 2007 with the intent of accelerating development and adoption of LIDAR. The project's objectives were to (a) describe requirements that must be met to use LIDAR data in aeronautical obstructions surveys and ALP elevation surveys; (b) recommend procurement specifications and procedures that could be used by airports or other agencies for procuring and using LIDAR data; and (c) describe the technical bases that could justify acceptance of LIDAR-based obstructions surveys by NOAA's National Geodetic Survey (NGS), FAA, airports, and airlines. The work entailed reviews of government guidelines and standards governing preparation of airport obstruction surveys, available equipment and procedures used by surveyors of airborne-LIDAR-based topographic surveys, and examples of LIDAR's application to conduct surveys at a number of airports. The research team then drafted the sample specification presented as an appendix to this digest. The sample specification may be useful to airport operators considering use of LIDAR. However, the FAA and NGS have not endorsed either the sample specification or LIDAR technology as a generally acceptable basis for conducting these surveys.

An obstruction survey may have a number of uses for an airport's development and management, including geodetic control for engineering projects, planning for site navigational aids, siting runway thresholds to meet approach obstacle clearance requirements, and supporting design and development of instrument approach and departure procedures and other flight operations information. Because of the critical nature of obstruction information for public safety, the FAA issues guidance for how obstructions surveys should be conducted and the specific formats and other characteristics of the geospatial airport and aeronautical data collected to support development of an obstruction survey. If an airport operator intends to use funds administered by the FAA under the Airport Improvement Program (AIP) or Passenger Facility Charge Program (PFC) to procure the obstruction-survey data or to use the data to demonstrate compliance with airport operations standards under CFR 14 Part 77, key provisions of FAA's guidance become mandatory. FAA's advisory circular "General Guidance and Specifications for Submission of Aeronautical Surveys to NGS: Field Data Collection and Geographic Information System (GIS) Standards" (AC 150/5300-18B; May 21, 2009) is the principal statement of the agency's requirements. AC 150/5300-18B represents a substantial revision of previously issued guidance and standards for obstruction survey data.

To date, there have been no FAA-authorized or -approved, third-party airport obstruction surveys prepared using LIDAR for data acquisition. Moreover, AC 150/5300-18B does not provide specific details for independent validation and verification procedures for LIDAR-based data. However, use of LIDAR is not precluded. The research conducted under ACRP Project 03-01 has shown that use of LIDAR may be cost effective.

LIDAR AND ITS APPLICATION IN AIRPORT SURVEYS

LIDAR is an active sensor technology, utilizing its own source of electromagnetic radiation (a laser), rather than relying on the sun as the source of illumination, as is the case with more traditional aerial

EXAMPLES OF THE USE OF LIDAR
FOR AIRPORT APPLICATIONS

GNV–Gainesville Regional Airport (2002)
RMN–Stafford Regional Airport (2003)
FDK–Frederick Municipal Airport (2003)
EEN–Dillant-Hopkins Airport (NA)
BMI–Central Illinois Regional Airport (NA)
AXV–Neil Armstrong Airport (NA)
ANE–Minneapolis/Anoka County-Blaine Airport, Janes Field (2005)
0A9–Elizabethton Municipal Airport (NA)
LNP–Lonesome Pine Airport (NA)
HKY–Hickory Regional Airport (2003)
SBA–Santa Barbara Municipal Airport (NA)
YVR–Vancouver Airport (NA)
48I–Braxton County Airport (2005)
SUN–Hailey Friedman Memorial Airport (2003)
PUW–Pullman Moscow Regional Airport (2003)
CLM–William R. Fairchild International Airport (2006)
VGC–Hamilton Municipal Airport (NA)
JAN–Jackson International Airport (2001)
TAN–Taunton Municipal Airport, King Field (NA)
SFQ–Suffolk Executive Airport (2008)
EDW–Edwards Air Force Base (2003)
S68–Laurel Municipal Airport (2007)
IMS–Madison Municipal Airport (2006)
DHN–Dothan Regional Airport (2006)
UNI–Ohio University, Snyder Field (2008)
3A1–Folsom Field Airport (2007)
RNO–Reno/Tahoe International Airport (2003)
10 Air Force Bases (1997-2002)

photography. As with its predecessor technology radar, LIDAR has proven to be an effective tool for a variety of survey and mapping applications. Airborne LIDAR in particular has emerged in recent years as a competitive alternative for topographic surveys and terrain mapping projects, especially for the survey of large areas. For example, the Federal Emergency Management Agency (FEMA) has developed procurement specifications for airborne LIDAR surveys for preparation of flood maps (FEMA, *Guidelines and Specifications for Flood Hazard Mapping Partners,* February 2002).

The research team conducted an extensive search to identify examples of the use of LIDAR to acquire data for airport applications. More than 30 cases were identified. (See text box for airport and year.) Three of the cases (Gainesville Regional Airport, Stafford Regional Airport, and Frederick Municipal Airport) were research studies sponsored by NGS and FAA. One of the cases (Suffolk Airport in Virginia) was found to have employed terrestrial LIDAR only. The research team concluded that at least 24 airports have been surveyed using airborne LIDAR, either as a research initiative (the Ohio University study or Braxton County Airport) or by commercial survey contractors. The research team was able to confirm that at least one commercial LIDAR survey was funded by the FAA, at William R. Fairchild International Airport at Port Angeles, Washington.

Survey contractors involved in these survey projects did not release information on specific survey costs and survey-design details for the cases identified by the research team. However, the research team was able to verify that a variety of vendors provide airborne LIDAR data collection and processing equipment and services suitable for use in an airport obstruction survey. Based on the limited information that could be assembled, the research team concluded that the cost of preparing an obstruction survey using airborne LIDAR is likely to be comparable to that of a survey prepared using traditional photogrammetry. Terrain, vegetation, and weather-related flight constraints have significant influence on costs for either technology. LIDAR may be used at night, which may offer cost savings and other advantages for data collection. Experience suggests that the costs per unit area of data collection with LIDAR may decline more rapidly than is the case with traditional methods as larger areas are surveyed. LIDAR may sometimes be used in conjunction with traditional photo-imagery.

LIDAR application yields very large data sets—"point clouds" of x-y location and elevation measurements at a high spatial resolution—that must be processed to yield a digital surface model (DSM) that presents terrain and obstruction identification information. Hardware and software are available to support the data processing and subsequent display of geographic information, but data-processing costs and technical challenges represent impediments to more rapid adoption of airborne LIDAR technology.

A particular concern in airport obstruction-survey applications is ensuring database compatibility with FAA requirements. While this research found evidence of LIDAR's application for airport obstruction surveys, there seems to be no consistent guidance; independent validation and verification; or quality control and quality assurance for the data collection, processing, and storage. The FAA has been understandably reluctant to accept LIDAR data into the Airports Geographic Information System (AGIS) and Third Party Survey System (TPSS) databases the agency uses to support the agency's airport and aeronautical information-development activities.

SAMPLE SURVEY SPECIFICATION FOR AIRBORNE LIDAR

A primary objective of ACRP Project 03-01 was to develop a sample specification that might assist airport operators and others in procuring obstruction surveys using LIDAR-based data. While research conducted by others and work in this project have suggested that LIDAR technology could become increasingly attractive for airport obstruction surveys, standardization of procedures and formats for data collection, processing, and storage is likely to be needed to accelerate the technology's adoption.

The research team found that commercial LIDAR survey contractors have typically incorporated stereo aerial imagery in their LIDAR workflow to enhance computational efficiency and facilitate accuracy checks and other quality control and assurance functions. Figure 1 illustrates a typical work process that might be followed for using aerial photography and LIDAR in an airport obstruction survey. A sample specification, developed by the research team and included as the appendix to this digest, assumes that stereo imagery will be available to support interpretation of LIDAR data.

The specification addresses four key aspects of data acquisition and processing:

- *Calibration tests:* Radiometric qualification tests for obstruction detection and system calibration (factory calibration, field calibration by flying over a building site of known topography, and in-flight calibration)
- *Survey planning calculations:* Grid and point spacing (along and perpendicular to the flight path), field of view, scanner angle and frequency, ground speed of the aircraft, swath width, number of flight lines, and line coverage perpendicular to the flight line
- *Flight mission planning parameters:* Coverage parameters (to ensure complete coverage of the required obstruction identification surface), swath overlap, flight line directions, flying height (as low as possible within the applicable eye-safety limits), and flight clearance
- *Airside geographic positioning system (GPS) data and landside ground GPS*: Data collection and processing

To collect high-resolution topographic data, LIDAR missions typically are flown at low altitudes, 1,000 m or lower. The flight path is planned to cover the study area and obtain the desired point spacing. The flight path includes both parallel and cross flight lines to eliminate shadowing, achieve desirable point density, and support proper quality control. Collection aboard the aircraft of GPS data using signals from at least four and ideally 12 satellites supports precise timing and GPS stamping. A LIDAR survey can generally be completed within 3 to 4 hours of flight time for a typical airport; in contrast to conventional aerial photography, LIDAR flights may be made during nighttime.

Airport operators or others considering use of airborne LIDAR-based surveys should ensure that the survey vendor is well qualified and experienced with the technology. The research team found that LIDAR-based airport surveys conducted to date have, for the most part, been conducted without oversight by NGS or FAA. Data from such surveys may not meet the quality control and quality assurance standards those agencies seek to maintain to ensure airspace safety. In the absence of clearly stated specifications and adequate data-quality assurance, the FAA is likely to remain reluctant to accept LIDAR data into the AGIS and TPSS databases. FAA requirements for remote sensing surveys are stated in AC 150/5300-18B.

Airport operators or others wishing to use FAA funding support to conduct a survey (or to have the data produced by the survey be accepted for obstruction identification) must meet the requirements of that circular or obtain FAA approval in advance to exceed or otherwise deviate from those requirements. The sample specification reflects the characteristics of LIDAR equipment and processes currently in use, but is designed to be flexible in accommodating higher resolution and otherwise more accurate data collection methods as industry innovation progresses. The research team concluded that benefits of using LIDAR are likely to increase and in some instances may already be sufficient to motivate a survey provider and airport operator to request this approval. In such a case, the sample specification may be a useful model for the survey's design.

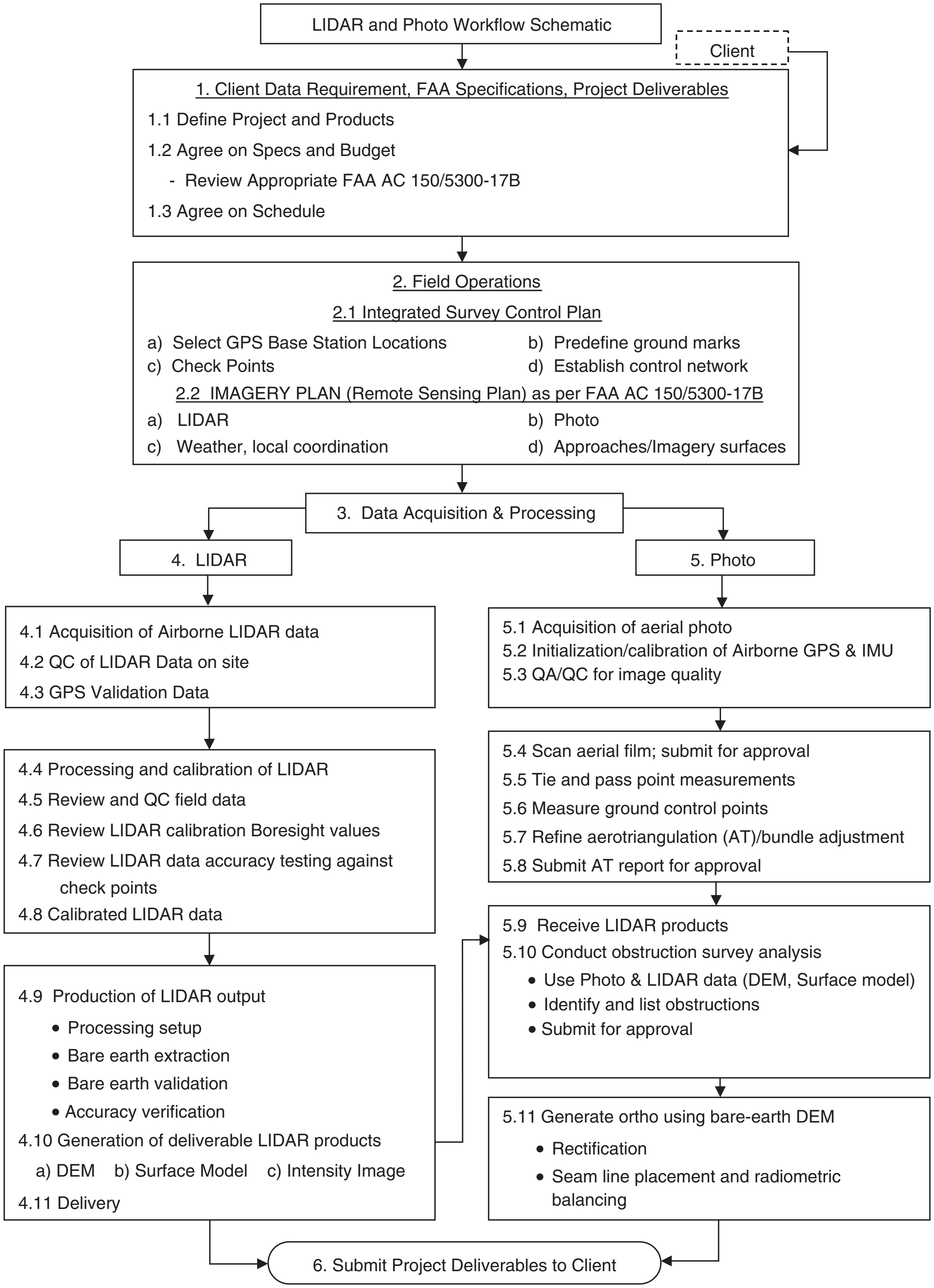

Figure 1 Typical workflow using aerial photo and LIDAR for obstruction survey. (Source: Derived from information provided courtesy of Terrapoint Aerial Services.)

APPENDIX

Light Detection and Ranging (LIDAR)

Sample Specifications of Airborne LIDAR for Airport Obstruction Surveys

The sample specifications and guidelines contained in this Scope of Work (SOW) document are intended for conducting airborne LIDAR surveys and using the point clo ud" data in combination with aerial imagery for airport obstruction analysis. However, this document is not approved by the Federal Aviation Administration at this time and it shall not be considered as an interpretation or statement of FAA policy. Contractors seeking information on FAA-approved airport obstruction survey standards are advised to contact the FAA directly.

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1 GENERAL

Airport obstruction surveys provide safety critical source data used by the Federal Aviation Administration (FAA) to develop instrument approach procedures, determine maximum takeoff weights for aircraft, update aeronautical publications, and perform other functions. The primary objective of an airport obstruction survey is to accurately geolocate objects and obstacles that may penetrate a specified FAA Obstruction Identification Surfaces (OIS). Penetrating objects are termed “airport obstructions.” Examples of typical types of obstructions include trees, buildings, towers, poles, antennas, and terrain. The Aeronautical Survey Program (ASP) of the National Geodetic Survey (NGS) established at National Oceanic and Atmospheric Administration (NOAA), under an interagency agreement with the FAA, has carried out obstruction surveys in the past using FAA 405, *Standards for Aeronautical Surveys and Related Products* (U.S. Dept. of Transportation, 1996). The FAA 405 document has been superseded by the current updated FAA Advisory Circular (AC) standards. The current FAA standards require NGS to conduct quality review and independent verification and validation of obstruction survey data. This Scope of Work (SOW) defines survey specifications and requirements for LIDAR data acquisition and processing to support the ASP. Additional project instructions included in contract agreement for an airport will provide project-specific survey information. General specifications, standards, guidelines, and additional requirements for airport obstruction surveys are contained in the following FAA ACs:

- AC 150/5300-16A, *General Guidance and Specifications for Aeronautical Surveys: Establishment of Geodetic Control and Submission to the National Geodetic Survey,* September 15, 2007.
- AC 150/5300-17B, *General Guidance and Specifications for Aeronautical Survey Airport Imagery Acquisition and Submission to the National Geodetic Survey,* US Dept. of Transportation, September 28, 2008.
- AC 150/5300-18B, *General Guidance and Specifications for Submission of Aeronautical Surveys to National Geodetic Survey (NGS): Field Data Collection and Geographic Information System (GIS) Standards*, US Dept. of Transportation, May 21, 2009.

The following conventions have been adopted for this SOW document. The term “shall” means that compliance is required. The term “should” implies that compliance is not required, but is strongly recommended. All times shall be recorded in Coordinated Universal Time (UTC). The Survey Acquisition Contractor (SC) shall be referred to as “Contractor” in the SOW document.

LIDAR data acquisition for airport obstruction surveying is very different than for other applications, such as floodplain mapping or bare-earth terrain mapping. For this reason, this document contains detailed information on collecting LIDAR data for obstruction survey purposes. The following list outlines some of the most important considerations in collecting LIDAR for airport obstruction surveys and references the corresponding sections of this document:

A. Multiple Look Angles. To achieve a high probability of detection and to assist in distinguishing between real objects and noise in the point cloud data, it is important to scan each section of the survey area from multiple look angles (i.e., different viewing geometries). One way to achieve this is using a combination of tilt (or “forward look”) angles. This method is advantageous in obstruction surveying in that it yields strong geometry (high point density on vertical objects) and radiometry (return signal strength), while simultaneously increasing probability of obstruction detection and reducing probability of false alarm (or “false objects”). (See Sections 4.1 and 5.2.)

B. Horizontal Point Spacing. The density of laser points on the ground is a key factor in the ability to detect obstructions. Airport obstruction surveys typically require “ultra-dense” LIDAR as compared with other applications, such as floodplain mapping. The horizontal point spacing in both the along-track and across-track directions must meet the specifications contained in this document. (See Section 5.1.)

C. Vertical Point Spacing. Because many obstructions are tall, small-diameter objects, such as poles, the vertical point spacing is also a key consideration. The vertical point spacing, defined as the vertical distance between points from consecutive scan lines on the face of a vertical surface, is only applicable to tilted systems. (See Section 5.2.)

D. Mission Planning. The mission parameters used in obstruction surveying are different than those typically used for other applications, such as bare-earth terrain mapping. In addition to choosing parameters that will meet the required horizontal and vertical point spacing, radiometric considerations (i.e., those related to the received signal strength) must be taken into account. To ensure that the received signal from small-diameter, low-reflectance obstructions, such as antennas or poles, will be above the receiver detection threshold, it is typically necessary to use a narrow beam divergence and fly as low as possible, taking into account eye-safety limits and other considerations. Additionally, swath overlap, cross-lines, and other mission planning parameters must be carefully planned based on the unique considerations involved in airport obstruction surveying, including precautions taken to avoid missed objects, as illustrated in Figures 9.1, 9.2, and 9.3. (See Sections 9.1 and 9.2)

E. Radiometric Performance. The radiometric performance of the LIDAR system is critical in obstruction detection in that the received signal from small diameter, low-reflectance obstructions (e.g., dark-colored poles and antennas) must be above the receiver detection threshold for these objects to be detected and successfully mapped. LIDAR systems to be used in obstruction surveying must pass the radiometric qualifications test described in this document. Section 6 contains a recommended radiometric qualifications test for LIDAR systems to be used in obstruction surveying, and Section 8.3 describes an additional *in situ* test of the system's ability to detect small-diameter, low-reflectance objects.

F. Processing. For airport obstruction surveys, it is critical that full LIDAR point cloud containing ALL laser returns be used (i.e., first, last, and all intermediate returns, with no points removed or filtered out). Additionally, it is absolutely critical to start with the data in point cloud format; interpolated digital surface models (DSMs) are unacceptable as input to the processing, since 2D grids of elevation values cannot adequately represent vertical structure. Additionally, it is important to emphasize high probability of detection, P_D, on vertical objects in any vertical object detection algorithm employed in the post processing (see Section 14). A generic OIS processing workflow is outlined Figure 14.1.

G. Imagery. Aerial photography (digital or film) is important in that it assists in attributing obstructions and in distinguishing real features from false returns, as well as providing an independent source data set for validation and verification. (See Section 11.)

2 GOVERNMENT (AIRPORT SPONSOR/FAA/NGS)

2.1 PROPERTY OF DATA

All original data, from the instant of acquisition, and other deliverables required through this contract, are and shall remain the property of the airport sponsor and/or United States Government, if not stated otherwise in project instructions. This includes data collection within and outside the project area. These items include the Contractor-furnished materials. Refer to AC 150/5300-18B for specific guidelines related to survey project administration and Contractor's responsibilities.

2.2 PROVIDED BY GOVERNMENT

The government will provide to the Contractor:

A. PROJECT INSTRUCTIONS – Project instructions are included in a separate document that provides specific project information, contains any unique project requirements, and may have the following attachments:

- Maps showing the project area
- OIS requirements

B. LIDAR SURVEY ACQUISITION REQUIREMENTS (this SOW document)
C. Surface Model Library (see Section 14.1)
D. REJECTED DATA – If data are rejected by FAA/NGS, sample data will be sent upon request showing the problem areas.

3 DELIVERY SCHEDULE AND DATA FLOW

3.1 REGULAR PRODUCTION

Any request to deviate from these standards shall be submitted, in advance of the data acquisition, to FAA/NGS for written approval.

3.1.1 DATA ACQUISITION STANDARDS

A. Global Positioning System (GPS) Position Dilution of Precision (PDOP) shall be <3.
B. Unless otherwise stated in the project instructions, horizontal along-track and across-track point spacing shall not exceed the limits specified in Table 5.1.
C. Unless otherwise stated in the project instructions, vertical point spacing shall not exceed the limits specified in Table 5.1.
D. Aircraft bank angle shall not exceed 20 degrees.
E. Other mission parameters including flightline and flying height shall be set based on the specifications contained in Section 9.1.

3.1.2 DATA PROCESSING

A. The format of the data shall be latitude, longitude referenced to the North American Datum of 1983 (NAD 83) and an epoch date shall be included, such as NAD 83 (1986) or NAD 83 (2007).
B. The vertical datum is the North American Vertical Datum of 1988 (NAVD 88). To conform to aeronautical conventions and FAA standards, elevation units are U.S. Survey feet.
C. The geoid model to be used in converting from GPS-derived ellipsoid heights to NAVD 88 orthometric heights is GEOID03 or the most current version. For Geoid information see: www.ngs.noaa.gov/GEOID.
D. <u>No points shall be removed (filtered out) from the LIDAR point cloud data</u>. Outliers shall be classified as “withheld” in the file, in accordance with the LAS file formatting requirements. (See Section 14.2).
E. The Contractor shall ensure complete coverage of the OIS. There shall be no “holidays” in the data (no data gaps) anywhere within the OIS.
F. The Contractor shall record all processing steps and software used including version numbers.
G. The Contractor shall use either Rapid or Precise orbits (but not UltraRapid orbits) for GPS processing.

3.1.3 ACCURACY STANDARDS

Accuracy requirements for airport surveys are a function of the survey type, which is specified by the FAA and listed in the individual project instructions. Additional information on accuracy requirements can be found in FAA Order 8260.19, *Flight Procedures and Airspace* (U.S. Department of Transportation, 1993). More recent information regarding these accuracy requirements and OIS is found in the following FAA ACs:

AC 150/5300-17B, *General Guidance and Specifications for Aeronautical Survey Airport Imagery Acquisition and Submission to the National Geodetic Survey, US Dept. of Transportation*, September 28, 2008.

AC 150/5300-18B, *General Guidance And Specifications For Submission Of Aeronautical Surveys To NGS: Field Data Collection And Geographic Information System (GIS) Standards*, US Dept. of Transportation, May 21, 2009.

To ensure high-quality data, the Contractor may be required to perform a standard accuracy assessment and/or obstruction detection accuracy assessment on the LIDAR data. The individual project instructions will list the specific requirements.

Minimum 30 accuracy checkpoints shall be used for LIDAR survey unless otherwise required in project instructions and these shall be referenced to the National Spatial Reference System. If Contractor proposes to perform less number of LIDAR accuracy checkpoints then prior permission shall be obtained in advance from FAA/NGS. Minimum nine imagery ground control points for georeferencing imagery and an additional minimum five accuracy checkpoints are required for aerial imagery/photo. The pre-marked imagery ground control points and accuracy checkpoints should be of suitable type and location such that they can be detected in both imagery/photo and LIDAR data sets. Accuracy checkpoints for LIDAR can be the same locations used for imagery accuracy checkpoints and imagery control GPS ground stations. These accuracy checkpoints are not to be confused with the ground GPS base station data required and used for post-processing airborne GPS data for both LIDAR and aerial imagery. (See Sections 13.1, 13.2, and 21.)

The standard accuracy assessment, if required, will be performed in accordance with the "ASPRS LIDAR Guidelines – Vertical Accuracy Reporting for LIDAR Data" (ASPRS, 2004) and the corresponding horizontal accuracy reporting guidelines. Only the "fundamental" vertical accuracy, as defined by ASPRS, needs to be calculated and reported; "supplemental" vertical accuracies for various ground cover classes do not need to be reported. Accuracy shall be reported at the 95% confidence level. All accuracy checkpoints shall be referenced to the National Spatial Reference System (NSRS) and, preferably, tied to the National Continuously Operating Reference Stations (CORS) network. These checkpoints are not to be confused with ground GPS ground control stations, but maybe georeferenced using standard GPS techniques as described in the ASPRS Guidelines.

In accordance with the ASPRS Guidelines (ASPRS, 2004), the checkpoints should be at least three times more accurate than the data being tested and should be well distributed throughout the dataset. The checkpoints should be located on open terrain of constant gradient for which the "first return" and "last return" elevations are equal. A final report shall be generated following this testing process and delivered to FAA/NGS. This report shall contain a table summarizing the results including the number of checkpoints, and the mean, median, mode, skewness, and standard deviation of the dataset, in addition to the $Accuracy_{(z)}$, as defined in the ASPRS Guidelines.

If obstruction detection accuracy assessment is required, the Contractor can contact NGS to obtain the analysis software and specifications, as well as the independent field-surveyed data set. Obstruction detection accuracy assessment is performed by comparing the LIDAR data against an independent high-accuracy field-surveyed obstruction data set. The software used in the obstruction accuracy assessment compares the data sets and computes the percent detection, as well as the horizontal and vertical RMSE for obstruction data points in the LIDAR data set. (See Section 8.)

3.2 DATA FORMAT AND STANDARDS

A. Format of deliverables shall be:

1. LIDAR point cloud: LAS 1.2 or more recent version of the LAS standard will be required and specified further in the project instructions. The LAS file shall contain all recorded returns (i.e. first, last, and any intermediate returns), return number, scan angle, scan direction, GPS time, intensity, X, Y, Z, and the edge of the flight line (if available). If digital aerial imagery is collected concurrently the LAS file may be version 1.2 and contain an associated red, green, blue (RGB) values (optional), as well as LIDAR intensity (required) for each LIDAR point. Details on LAS format standards can be found at: http://www.asprs.org/society/committees/LIDAR/LIDAR_format.html. <u>No points shall be removed</u> from the LIDAR point cloud.
2. "Raw" observation files (i.e., laser ranges, scanner angles, position and orientation data, with applicable time tags, waveforms if available, etc., as taken off the aircraft at the end of the flight) enabling NGS to post-process the raw data to generate point clouds.
3. Imagery: GEOTIFF (see Section 11). Follow AC 150/5300-17B specifications.

B. The media for deliverable shall be an external Hard Drive (either SATA or eSATA format) formatted NTFS. Contractor shall maintain a copy of the data until FAA/NGS acknowledges receipt and confirms data is valid.

3.3 DATA FLOW

Survey Acquisition Contractor, referred to as SC or Contractor, shall submit survey plan and quality control plan to Airport Authority/FAA for NGS review. Survey work is authorized by Airport Authority only after approval from FAA. Survey data shall be handled in the following sequence:

A. SC acquires data as per SOW and FAA accuracy requirements.
B. SC processes data to FAA/NGS specifications.
C. SC validates data versus check points.
D. SC ships data to FAA/NGS as per SOW.
E. FAA/NGS receives data, acknowledges receipt of data, reviews data, conducts verification and quality checks, and notifies SC of review outcome.
F. If during the FAA/NGS review, the data are found to not meet the SOW, the Contractor may be required to re-acquire the data.

3.4 COMPLETION DATE

All deliverables shall be received by FAA/NGS, as specified, no later than the date in the project instructions.

4 EQUIPMENT AND MATERIAL

4.1 LIDAR SYSTEM

The Contractor shall have several options in deploying the LIDAR sensor for OIS surveys (see Table 4.1). The following alternatives describe preferred and optional approaches, all accepted by FAA/NGS. Note: In Table 4.1 for true sensor-fusion-based methods, the distinction between “photo-assisted LIDAR workflow” and “LIDAR-assisted photogrammetric workflow” becomes somewhat ambiguous. However, for purposes of this document, the determining factor in distinguishing between these two types of workflows is which sensor the Contractor certifies as the “primary” source of obstruction information.

A. MULTI-LOOK GEOMETRY - It is recommended that the LIDAR data be collected using two look angles (nadir and 20^{o} forward). This approach can be met either with a custom dual-look system (i.e., a LIDAR system designed specifically for obstruction surveying utilizing dual lasers, each with a different look angle) or by using a variable-tilt sensor mount (Figure 4.1) and flying the project area twice: once in each configuration. Using two different collection geometries is important for the following reasons:

1. The nadir-pointing and tilted sensors complement each other in that the tilted sensor provides better geometry (laser points that “walk up” the face of a vertical object), while the nadir-pointing sensor yields higher return signal strength from small obstructions.

2. The dual-look approach assists in distinguishing between “false returns” (i.e., unwanted returns caused by atmospheric particles, birds, electronic noise, etc.) and real features (e.g., the top of a power pole) in that it is unlikely that the same false point would be registered with both geometries.

3. The dual-look LIDAR survey approach enhances vertical point spacing.

Figure 4.1 Example of a variable-tilt sensor mount. One method of achieving the dual-look approach is to fly the project area twice (once in each configuration) using a variable-tilt mount

The enhanced obstruction detection geometry afforded by this LIDAR acquisition approach allows the imagery requirements to be slightly "relaxed" (see Table 4.1).

Table 4.1 Options for deploying nadir or tilted sensors

LIDAR Option	System Description	General Workflow Description
Multi-look via tilted sensor	• Deploy either simultaneous twin-look sensor or tilt-mount and fly two sets of passes at nadir and at 20° • Cross/tie lines at end(s) of each runway(s) • Relaxed imagery requirements	Photo-assisted LIDAR workflow. Proceed with OIS analysis steps as suggested in Figure 14.1.
Multi-look via redundant, orthogonal passes	• First set of passes parallel to runways • Second set of passes perpendicular to first set • Relaxed imagery requirements	Photo-assisted LIDAR workflow. Proceed with OIS analysis steps as suggested in Figure 14.1.
Single-look, relying primarily on photogrammetric methods for obstruction detection	• First set of passes parallel to runways • Cross/tie lines at end(s) of each runway(s) • Stringent imagery requirements	LIDAR-assisted photogrammetric workflow. Introduce image data earlier in workflow. Rely principally on photogrammetric methods to detect vertical obstructions (VOs), LIDAR is used to supplement processing and for DEM and orthophoto generation.

B. ALTERNATIVES TO DEPLOYING MULTI-LOOK LIDAR SYSTEM

1. ALTERNATIVE #1 - The Contractor shall fly parallel flight lines (with 50% swath overlap) in opposing directions (reciprocal headings), then fly perpendicular flight lines, again with 50% swath overlap in an alternating heading pattern, covering the entire OIS. This will ensure redundant, multi-look coverage comparable to, although slightly less desirable than, a tilted sensor deployment. In this case, camera imagery with "relaxed" resolution (as compared with Alternative #2) up to 0.50 m may be used to satisfy the imagery requirement in Sections 11 and 14.

2. ALTERNATIVE #2 - The Contractor shall fly parallel flight lines (with 50% swath overlap) in opposing directions (reciprocal headings). At least one cross/tie line shall be flown over each end of each runway/approach (e.g. airport with two runways will have four cross/tie lines). The lack of multi-look geometry from the LIDAR will be compensated by the more stringent photogrammetric analysis of the imagery. In this case, the imagery will be utilized at a much earlier step in the post-processing workflow (prior to performing OIS analysis), so that all objects potentially missed by the LIDAR will be identified, analyzed, and attributed using the imagery. (Refer to Section 14.1, Figure 14.1.) The Contractor shall adhere to the imagery specifications outlined in AC 150/5300-17B. Additionally, imagery resolution shall be 0.10 m or better.

C. MAINTENANCE – Prior to commencing data acquisition, the contractor shall provide to NGS: certification that both preventive maintenance and factory calibration have been completed either in accordance with the manufacturer's scheduled intervals, or as justified by apparent lack of calibration stability, whichever interval is shorter.

D. DATA COLLECTION
1. Carrier-phase L1 and L2 kinematic GPS shall be acquired and used in processing the trajectories. See Section 13 for further details.
2. The LIDAR system must acquire and output "intensity" data (i.e., data values proportional to the amplitude of each laser reflection).
3. The LIDAR system shall be capable of meeting the point spacing requirements specified in Section 5.
4. Sensor-to-GPS-antenna offset vector components ("lever arm" values) shall be determined with an absolute accuracy (1,) of 1.0 cm or better in each component. Measurements shall be referenced to the antenna L1 phase center. The offset vector components shall be re-determined each time the sensor or aircraft GPS antenna is moved or repositioned in any way. Note: with a variable-tilt sensor mount, as shown in Figure 4.1, it is typically necessary to re-determine the sensor-to-antenna offset vector each time the sensor is tilted or for each fixed tilt setting.

E. MALFUNCTIONS – All LIDAR system malfunctions shall be recorded, and FAA/NGS shall be notified. A malfunction is defined as a failure anywhere in the LIDAR sensor that causes an interruption to the normal operation of the unit. Also, any malfunctions of the GPS or Inertial Measurement Unit (IMU) collection systems shall be recorded and reported.

4.2 AIRCRAFT

A. PLATFORM TYPE – The type of aircraft and the aircraft tail number used shall be stated on the LIDAR Flight Log and all aircraft used in the performance of this Project shall be maintained and operated in accordance with all regulations required by the FAA. Any inspections or maintenance of the aircraft which results in missed data collection shall not be considered as an excusable cause for delay.

B. PORT OPENING – The design of the port opening(s) in the aircraft shall be such that the field of view is unobstructed when a sensor is mounted with all its parts. The field of view, as much as possible, shall be shielded from air turbulence and from any outward flows, such as exhaust gases, oil, etc. The port opening shall not contain any type of window (including optically-flat windows). The sensor shall have a clear view of the ground below, and no optics other than those internal to the LIDAR system and installed by the LIDAR manufacturer shall be placed in the optical path of the laser beam. This requirement is due to the fact that some attenuation of the laser radiation will occur even with coated, optically-flat windows, which could lead to non-detection of obstructions.

5 POINT SPACING

The spacing of the LIDAR data points is a critical factor in the ability to detect obstructions. Both the horizontal and vertical point spacing (defined in Sections 5.1 and 5.2, respectively) shall meet the specifications contained in Table 5.1, unless otherwise stated in the project instructions.

5.1 HORIZONTAL POINT SPACING

Horizontal point spacing refers to the spacing of the LIDAR points on a flat surface. Horizontal point spacing is defined along two directions: along track (i.e., in the direction of flight) and across track (i.e., perpendicular to the direction of flight). The horizontal along-track point spacing, HPS_{along}, is given by

$$HPS_{along} = \frac{\nu}{2f_{sc}} \tag{5.1}$$

where ν is the flying speed over ground and f_{sc} is the scan frequency. The horizontal across-track point spacing, HPS_{across}, is given by

$$HPS_{across} = \frac{\text{swath width}}{\text{number of points per scan line}} \tag{5.2}$$

$$= \frac{2H \tan(^{S}/_{2})}{PRF(^{\tau_{sc}}/_{2})}$$

where H is the flying height, S is the full scan angle, PRF is the pulse repetition frequency, and τ_{sc}, is the period of the scanner (i.e., the inverse of the scan frequency).

Unless otherwise stated in the project instructions, horizontal point spacing must meet the specifications contained in Table 5.1 of this document.

5.2 VERTICAL POINT SPACING

Vertical point spacing is only applicable in the case of a tilted sensor. Vertical point spacing refers to the vertical distance between points from consecutive scan lines on the face of a vertical surface. Vertical point spacing, VPS, is given by

$$VPS = \nu\tau_{sc} \cot(t) \tag{5.3}$$

Where, ν is the flying speed over ground, τ_{sc} is the period of the scanner, and t is the tilt (or "forward look") angle.

Unless otherwise stated in the project instructions, the vertical point spacing must meet the specifications contained in Table 5.1 of this document. Note: depending on the system used, achieving these point densities may require multiple passes. In this case, it is recommended that both parallel and perpendicular lines be flown, as recommended previously for the nadir-only sensor in Section 4.1.

Table 5.1 Point spacing specifications

	Maximum Across-Track Horizontal Point Spacing	Maximum Along-Track Horizontal Point Spacing	Maximum Vertical Point Spacing (tilted Sensors only)	Corresponding Point Density
LIDAR survey supplemented with aerial photography (digital or film)	0.18 m	0.18 m	0.50 m	30 points/m^2

6 RADIOMETRIC QUALIFICATION TEST

This section describes a recommended test and proposed equipment to be developed and maintained at NOAA/NGS. At present, this equipment has not been constructed, so the responsibility for performing this test, if required, is solely that of the Contractor.

The objective of the test procedures described here is to radiometrically qualify LIDAR systems for airport obstruction surveying. The outputs of this test are the maximum qualified operating height, h_{max}, for the system and the minimum ground sampling density, δ_{min}, for that system. This test qualifies an individual, unique system, and it is not intended as a type qualification test.

This test is constructed for single-beam, scanned-spot architecture, 1064nm LIDAR instruments, and any other instrument architectures proposed for use should be qualified in the spirit of this test. For example, a multi-beam LIDAR system would require a measurement for each beam in the system and the result would require flight planning based on the worst-case maximum flying height and the worst-case sample density, even if they result from different beam data elements. Instruments designed to operate at different wavelengths (e.g. 1540 nm) would require a reflectance standard with Lambertian characteristics and would require a measurement of ρ_0, the target reflectance, at the operating wavelength.

The radiometric performance of a LIDAR system is critical in obstruction detection. Systems qualified by this test, and operated at an altitude above-ground-level (AGL) less than or equal to the maximum operating altitude (calculated by the methodology of this section) and at a sample density greater than or equal to the minimum operating density (calculated by the methodology of this section) have a high likelihood of detecting small-diameter, low-reflectance obstructions, such as dark-colored poles and antennas.

The test procedures have been designed to meet the following requirements:

- Provide a common reference so that the results from different manufacturers' LIDAR systems will have the same meaning.
- Provide a method that specifically tests the ability of the LIDAR system to detect small-diameter obstructions, such as antennas and poles.
- Utilize a ground-based, controlled test environment.
- Ensure repeatability of the results.

This test will be carried out under the oversight of NOAA personnel at the proposed NOAA LIDAR Radiometric Calibration Center at Corbin, VA, unless written consent is granted by NOAA for the Contractor to perform an in-flight radiometric performance test in lieu of the test described below. The test setup is illustrated in Figure 6.1.

The test target consists of a one-half inch diameter wood dowel painted with Kodak White Reflectance Coating. This coating provides a standard reflectance of nearly 100% at a 1064 nm wavelength and has Lambertian reflectance properties.

A minimum of two configurations shall be tested; 1) with the LIDAR directed to its nadir position and, 2) with the LIDAR directed to the maximum angular excursion planned for the OIS survey activity. The intention of measuring at multiple angular positions is that the internal optical characteristics of the LIDAR instrument may not allow equal radiometric efficiency at different scan angles. This test is intended to determine the minimum return signal within the planned operational angular range for the instrument under test.

For the first portion of the test, the target is placed at a known distance of R_0 = 100 m and positioned such that it intercepts the transmitted beam approximately at the center of the beam. The dowel must be long enough to cross the entire beam spot diameter.

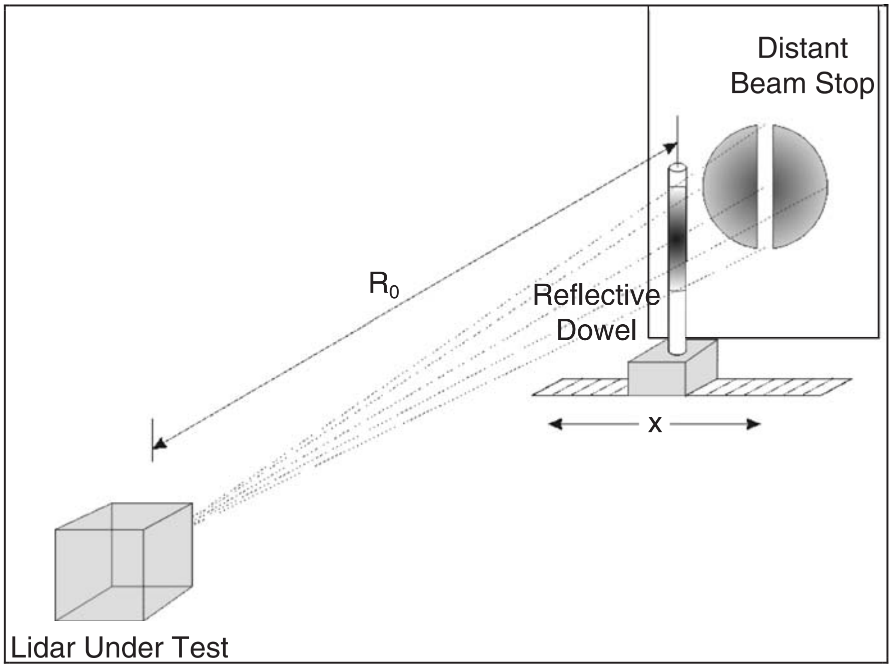

Figure 6.1 Setup for radiometric qualifications test to be performed at the NOAA LIDAR Radiometric Calibration Center at Corbin, VA.

For each angular condition tested, the laser shall be fired at the test target for at least 10 seconds and the return signal shall be recorded. The minimum measured first-pulse intensity recorded during any of the angular setups shall then be scaled to correspond to the actual planned flight parameters using:

$$I_s = I_0 \left({}^{R_0}/_{R_{max}} \right)^3 \left({}^{\rho_{min}}/_{\rho_0} \right) \qquad (6.1)$$

where I_s is the scaled, worst-case first-pulse intensity expected in operation,
I_0 is the minimum measured first-pulse intensity recorded during the test,
R_0 is the test range (100 m),
R_{max} is maximum range for the planned flight parameters,
ρ_0 is the reflectance of the standard target (1 at 1064 nm with the Kodak White Reflectance Coating),
and ρ_{min} is the "worst-case scenario" reflectance, assume 5%.

R_{MAX} is calculated from:

$$R_{MAX} = {}^{h_{max}}/_{\cos t \cos s} \qquad (6.2)$$

where h_{max} is the maximum flying height (AGL),
t is the tilt ("forward look") angle,
and s is the maximum half scan angle from the flight plan.

By defining two correction factors and rearranging to isolate h_{max}:

$$h_{max} = R_0 \cos t \cos s \Big/ \left(I_s \rho_0 f_a f_{sm} \big/ I_0 \rho_{min} \right)^{\frac{1}{3}} \tag{6.3}$$

where f_{sm} sets an acceptable safety margin (usually 110%), and f_a is an atmospheric loss correction factor in the range 1.1-1.3 ($f_a = 2.86x10^{-4}h + 0.9$).

7 SPOT SPACING QUALIFICATION TEST

A follow-on to the radiometric testing (leveraging the radiometric test setup) will calculate the minimum required sample spacing for the system being qualified. The setup for this test is the same as the first part, but the horizontal position of the target will be adjusted to find the detectable limit of the LIDAR on each side of the beam.

The target shall be removed from the beam to one side and slowly introduced to the illuminated area. The system under test must be monitored until it is indicating valid ranges at R_0 without dropouts (dropout count/readout ≈ "0") indicated. The intensity reported, I_1, shall be recorded. The target shall be translated to the other side of the beam until the system indicates dropouts (dropout count/readout ≠ "0"). The intensity, I_2, shall be recorded. The target shall be translated out of the beam on this side, and then the process repeated in the other direction to measure I_3 and I_4. If valid ranges are reported at intensity values of 0, the intensity values must be recorded as the least non-zero value possible (normally a gray scale value of 1).

The half maximum intensity shall be calculated by:

$$I_{HM} = \frac{1}{2}\left(I_0 + \frac{1}{4}\sum_{n=1}^{4} I_n\right) \tag{7.1}$$

The horizontal position of the half maximum intensity points shall be measured by the same target translation technique used to measure the minimum detectable intensities. The average of the two horizontal measures will be used to calculate the angular full width at half maximum, FWHM, of the beam by:

$$x_0 = \frac{1}{2}\left(|x_1 - x_2| + |x_3 - x_4|\right) \tag{7.2}$$

$$\phi_{FWHM} = 2 \tan^{-1}\left(x_0 / 2R_0 \right) \tag{7.3}$$

By noting that the LIDAR divergence angles are usually very small, Equation 7.3 can be approximated as:

$$\phi_{FWHM} \cong x_0 / R_0 \tag{7.4}$$

Then, the minimum sample density requirement for this system shall be:

$$\delta_{min} \cong (\phi_{FWHM} \cdot h_{max})^{-2} \tag{7.5}$$

When this test has been carried out under the oversight of NOAA personnel at the NOAA LIDAR Radiometric Calibration Center (LRCC) at Corbin, VA, then the NOAA observer will provide a signed Certificate of Qualification for the system under test, including a description of the system, the serial number of the system, the date of the system test and the values of the system's qualified parameters (h_{max} and δ_{min}).

8 SYSTEM CALIBRATION

Inadequate calibration or incomplete calibration reports shall be cause for rejection of the data by FAA/NGS. Calibration reports for each LIDAR system used shall be supplied to NGS at the beginning and end of the project. The calibration reports shall cover each of the following types of calibration:

8.1 FACTORY CALIBRATION

Factory calibration of the LIDAR system shall address both radiometric and geometric performance and calibration. (Note: the factory radiometric calibration does not obviate the need for the radiometric qualification test for obstruction surveying described in the previous section). The following briefly describes the parameters to be tested according to test procedures defined by the manufacturer. Some of these procedures and parameters may be unique to a manufacturer since hardware varies from manufacturer to manufacturer.

A. Radiometric Calibration (sensor response):

- Ensure that the output of the laser meets specifications for pulse energy, pulse width, rise time, frequency, and divergence for the model of LIDAR being tested.
- Measure the receiver response from a reference target to ensure that the response level of the receiver is within specification for the model of LIDAR system being tested.
- Check the alignment between transmitter and receiver and certify that the alignment is optimized and within specification.
- Measure T_0 response of receiver (i.e., the response at the time the laser is fired) to ensure that the T_0 level is within specification.

B. Geometric Calibration:

- Range Calibration – Determine rangefinder calibrations including first/last range offsets, temperature dependence, and frequency offset of rangefinder electronics, range dependence on return signal strength. Provide updated calibration values.
- Scanner Calibration – Verify that scanner passes accuracy and repeatability criteria. Provide updated scanner calibration values for scanner offset and scale.
- Position Orientation System (POS)-Laser Alignment – Alignment check of output beam and POS. Also, provide updated POS misalignment angles.

Overall, the system shall be tuned to meet the performance specifications for the model being calibrated. The Contractor shall ensure that, for each LIDAR system used, factory calibration has been performed within the manufacturer's recommended interval or more frequently, if required to demonstrate a stable calibration to NGS. Contractors who wish to apply for a waiver for this requirement must send a written request to NGS stating the date of the last factory calibration and a detailed justification for the waiver.

8.2 BORESIGHT/IN-SITU CALIBRATION

Sensor calibration is required to reduce or eliminate systematic errors in the LIDAR data. Specifically, the calibration procedures involve solving for a set of calibration parameters that minimize the mean square error (or satisfy some other statistical optimality criterion) using ground control and data in overlapping swaths. The specific set of calibration parameters is a function of the optical sensor model for the specific system, but may include, for example: roll, pitch, and range offsets, scanner scale and offset, or higher order polynomial coefficients. If performed properly, this calibration will ensure the highest possible data accuracy, while also eliminating artifacts in the data, such as discontinuities (vertical jumps) in swath overlap areas near the edges of scan lines, horizontal offsets between peaked rooftop positions in data from opposing flightlines, etc. This calibration shall be performed for each project or every month, or as dictated by analysis of the data, whichever interval is shortest.

Additionally, any calibration procedure that employs software shall be documented and the reports generated by the software shall be supplied to NGS along with a basic description of the software.

8.3 FIELD TEST/VALIDATION

The Contractor shall place a special test device within the survey area so that a validation of the system performance can be made. The device will simulate real-world conditions of potential objects that might intersect and protrude above the OIS and should be detectable by the LIDAR sensor. LIDAR point cloud data of the object should appear in the complete dataset.

8.3.1 Apparatus & Configuration

The equipment apparatus shall consist of the following materials:

1. A base plate or tube approximately 10' in length
2. (2) 6" diameter sections of PVC pipe, 8' in length, (1) black-color, (1) white-color
3. (2) 4" diameter sections of PVC pipe, 8' in length, (1) black-color, (1) white-color
4. (2) 2" diameter sections of PVC pipe, 8' in length, (1) black-color, (1) white-color

The 8' PVC sections shall be vertically mounted to the base plate/support such that they are oriented 90° with respect to the terrain level. The base plate must have two marks, one at each end, to geolocate the test apparatus once installed in the survey area. Refer to Figure 8.1 for an example.

The Contractor has latitude in selecting the PVC materials from different sources and for using readily available paints to paint with. However, all materials and their sources/suppliers MUST be approved, in advance, by NGS.

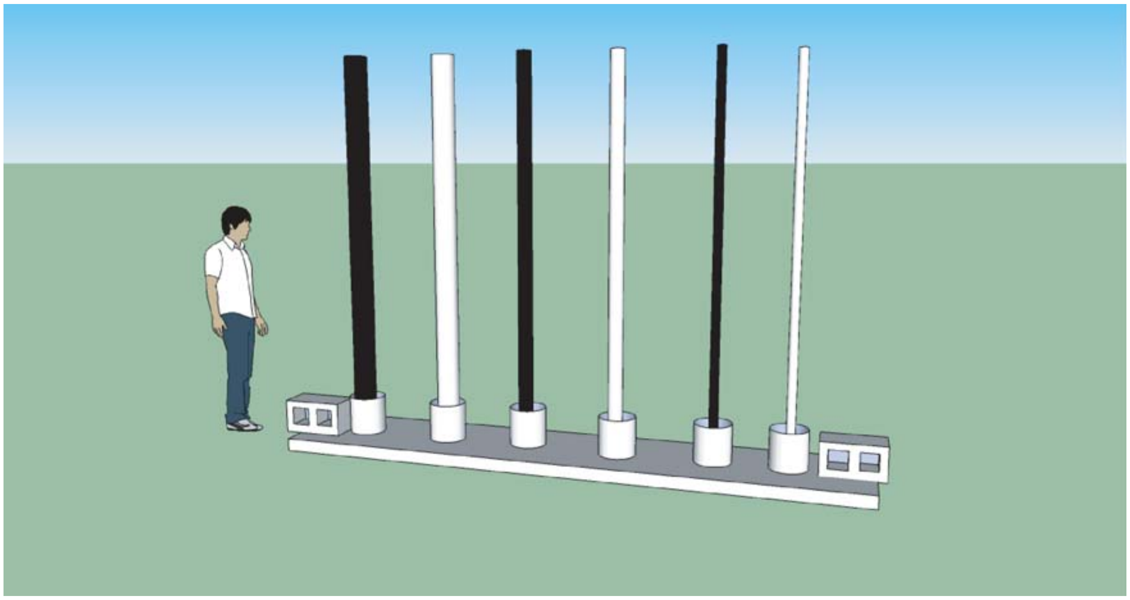

Figure 8.1 Example of test apparatus deployed in survey area, stabilized by supports and weights.

8.3.2 Placement

As practical as possible, the test device shall be placed in a safe, open area, within a normal section of the OIS survey area. It should be placed on level terrain or surface as is practicable. The structure shall be supported if necessary by sand bags or other means so that the device will remain erect and stable during severe wind conditions and so that it is not prone to be toppled by passers-by, etc.

8.3.3 Flight Regime

The Contractor shall only use the standard mission parameters planned for the survey. No extra data may be collected of the test apparatus location, and no special maneuvers nor flight plans may be used to enhance or "densify" data distribution on the test object.

9 MISSION PLANNING AND CLEARANCES

9.1 MISSION PLANNING

A. COVERAGE AND PARAMETERS – The Contractor shall plan flight lines for the project area (described in the project instructions) and ensure complete coverage of the OIS. The horizontal along-track point spacing, horizontal across-track point spacing, vertical point spacing, swath width, swath overlap, navigation, GPS, point density, radiometric considerations, and flying rules such as visibility shall be taken into account in flight planning. NGS may supply recommendations and/or requirements for planning parameters in the project instructions.

The planning of an OIS survey is not like the planning of a terrain survey. The objective is not to achieve the most efficient coverage within a bounding box on a 2D coordinate basemap. This activity requires the capture and identification of objects that project above an abstract and complex-shaped surface which is described above the terrain. The two figures attached in this section help to illustrate the objective, and the risk of failure that a traditional planning method might introduce.

The first illustration (Figure 9.1) presents a cross-section of the terrain taken through a runway and extending to the sides. The cross-section of the OIS is indicated in red and the terrain in brown. Vertical lines are edge delimiters for the OIS, analogous to the bounding box edges in a traditional plan. Based on a conventional survey plan, the survey might be executed in three passes, with a small edge-lap to efficiently cover a terrain survey. However, if this plan were actually used for the OIS survey, the tower on the left edge would be missed and the tree on the right edge would be under-represented. Both objects exist within the OIS and must be fully presented in the data.

The second illustration (Figure 9.2) changes the plan to include data collection beyond the traditional limits of topographic collection to enable the inclusion of the full height of the tower and a complete representation of the tree. The most important difference between the two plans is that the second has accounted for the need to capture all objects extending above the OIS and recognized that the scanned LIDAR beam has a maximum vertical extent which is a function of the scan angle. Capturing the entire vertical extent of any objects above the OIS's horizontal extents is a requirement, so the volume sampled must extend well above the abstract surface itself.

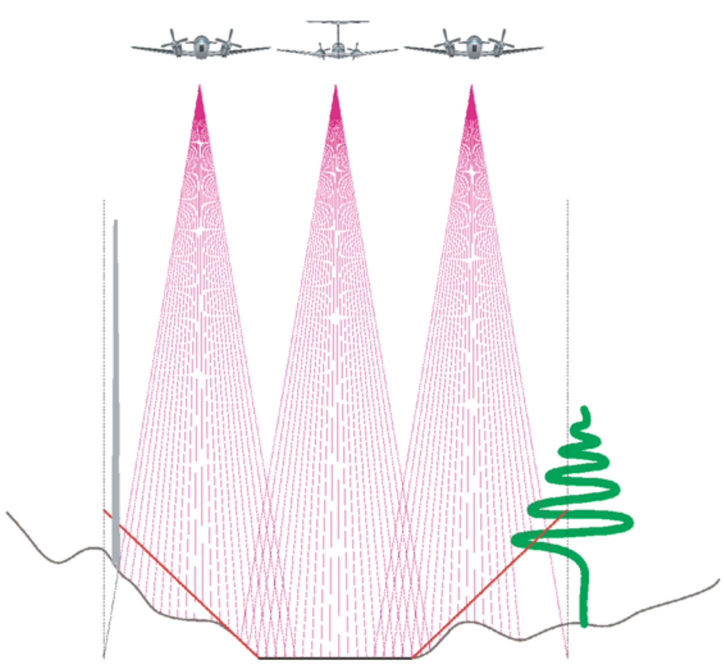

Figure 9.1 Three line survey of hypothetical OIS Surface

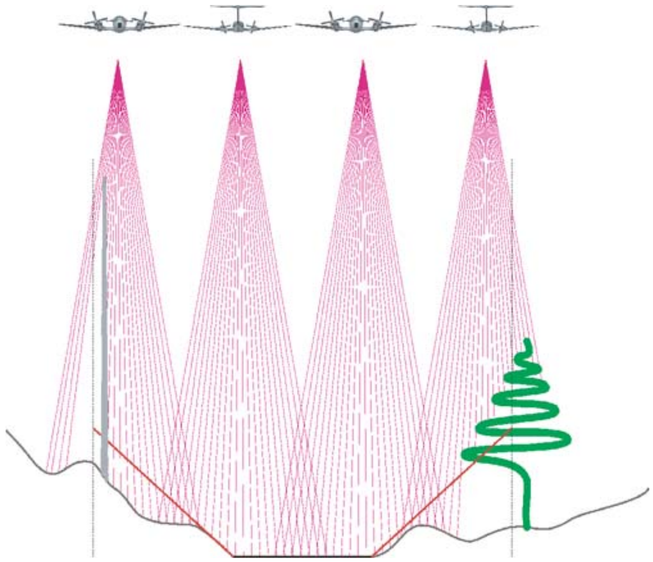

Figure 9.2 Four line survey of hypothetical OIS surface

Although not as common, a related problem that can occur is missing or under-reporting the tops of very tall objects, which fall between the FOVs of adjacent swaths, as shown in Figure 9.3. This can be mitigated with increased swath overlap and perpendicular cross-lines. However, since this problem typically only affects the very tallest objects in the scene (e.g., 300-m TV broadcast towers), and since these extremely tall objects are typically known to exist in the scene prior to the survey, special care can be taken in project planning to ensure they are adequately captured (e.g., with a flight line directly overhead).

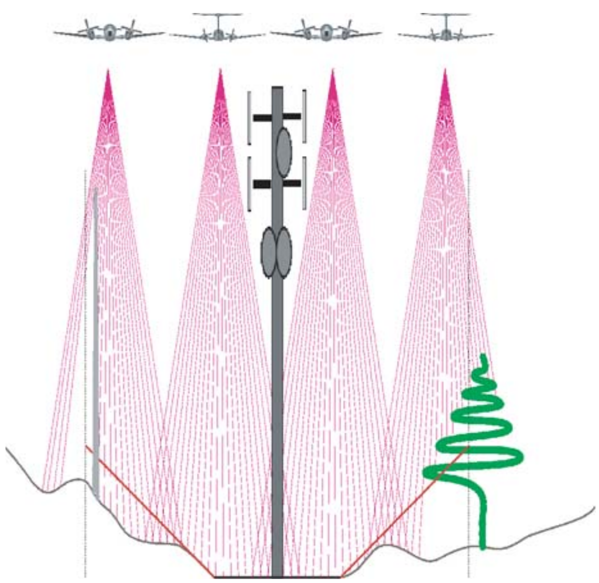

Figure 9.3 Depiction of tower between scan fields-of-view

B. SWATH OVERLAP – Adjacent swaths shall have a minimum overlap of no less than 50% of the mean swath width.

C. FLIGHT DIRECTION – Flight lines shall be flown in either direction; however, adjacent, parallel lines should be flown in opposite directions (reciprocal aircraft headings) to help in identifying systematic errors.

D. CROSS LINES – At a minimum, one crossline (orthogonal to the "primary" flight lines) per runway approach is required (even if a tilted sensor is used) in order to assess internal consistency and calibration. If a nadir-only sensor is used, the entire survey area shall be covered with cross-lines, as discussed previously in Section 4.1 (except when using the LIDAR-assisted photogrammetric workflow, as described earlier). If only one cross-line is flown, it shall be placed at the beginning of the approach, since this will provide higher data density in the area where the greatest threat from obstruction intrusion may take place.

E. WAVEFORM DIGITIZATION – Full-waveform data is recommended, and may be required by the Project Instructions. NGS research has shown that full-waveform LIDAR data can provide significantly more information about vertical structure, thereby assisting in the detection and recognition of objects in the survey site. If full-waveform data are to be utilized, the contractor shall submit a description of the waveform post-processing strategy to NGS prior to the survey.

F. LIDAR SURVEY PLAN REPORT

1. PROPOSED FLIGHT LINES – Prior to data acquisition, the contractor shall submit paper map(s), or shapefiles, or KML/KMZ files clearly showing all proposed flight lines, and also depicting coverage, proposed ground control, and OIS boundaries. Information about scan angle, pulse repetition frequency (PRF), flying height, flying speed over ground, and horizontal and vertical point spacing shall also be included.

2. ACTUAL LINES FLOWN – Similar map(s) showing the actual flight lines shall be included in the Final Report (see Section 13).

9.2 FLYING HEIGHT

Flying height is an extremely important factor in obstruction detection in that the received power from obstructions falls off as the 2nd, 3rd or 4th power of the range, depending on the laser radar cross section of the target. Hence, to ensure a high-probability of obstruction detection, it is typically desirable to <u>fly as low as possible</u>, within the applicable eye-safety limits. Depending on the airport and the minimum eye-safe altitude, this may necessitate airspace coordination.

9.3 FLIGHT CLEARANCES

The Contractor shall comply with all required FAA Regulations, including obtaining all required clearances.

10 EYE SAFETY

Because LIDAR systems typically employ Class 4 lasers, safety is a paramount concern. American National Standards Institute (ANSI) standards for safety shall be followed. See ANSI Z136.1 *Safe Use of Lasers* and ANSI Z136.6 *Safe Use of Lasers Outdoors* for applicable standards. For further details regarding safety issues in LIDAR data collection, refer to *Eye Safety Concerns in Airborne LIDAR Mapping* (Flood, 2001). The contractor shall assume sole responsibility for adherence to all safety regulations and shall implement necessary internal controls to ensure the safety of all persons in the aircraft and in the survey area below.

11 IMAGERY

Stereo aerial photography, collected with a film or digital mapping-grade (geometrically calibrated and stable) camera, is an important complement to the LIDAR data in that it enables the following functions to be performed:

- Quality assurance/quality control
- Feature attribution
- Outlier removal
- Independent obstruction identification/measurement

Imagery shall be collected in accordance with the AC 150/5300-17B, unless otherwise stated in the project instructions. Imagery acquisition shall be performed by the Contractor no later than 2 weeks following the completion of the LIDAR data acquisition, and no earlier than 2 weeks prior to the commencement of the LIDAR acquisition. No exception to the ± 2 week window is allowed without prior written approval from NGS or unless waived in the project instructions. If an aerial stereo imagery of the project area has been collected within 6 months prior to the LIDAR survey project then airport sponsor/survey contractor may propose its use with the LIDAR survey data. Prior permission and approval shall be obtained from FAA/NGS for this deviation from the above specification for acquisition of new imagery.

To the extent possible, ground control for the imagery and LIDAR data should constitute the same set of points. Standard photo targets (traditionally used for aerotriangulation and not widely used with a direct georeferencing subsystem), also provide a suitable target for the LIDAR. Due to the high reflectivity and large size, these targets are not only observable in the aerial imagery collected with a camera, they also appear as high-intensity (on a standard grey scale) points in a LIDAR point cloud. Photo control shall meet the requirements outlined in AC 150/5300-17B. In any case, it is strongly recommended that suitable types and locations for control be used such that they are readily identifiable in BOTH the imagery and LIDAR data. (See Section 21 for terminology related to ground GPS data collection.)

Ground control points shared between the LIDAR data and imagery, and those collected for LIDAR only, shall be tied to the National Spatial Reference System (NSRS), referenced to NAD 83, and shall have horizontal and vertical accuracies, at the 95% confidence level, of 10 cm and 20 cm, respectively.

12 WEATHER AND TIME OF YEAR

12.1 WEATHER CONDITIONS

LIDAR data acquisition missions shall be flown in favorable weather. Inclement weather conditions such as rain, snow, fog, mist, high winds, and low cloud cover shall be avoided. In addition, to ensure low atmospheric attenuation and high return signal strength, Visual Meteorological Conditions (VMC) and visibility of at least 8 nm are required. If clouds are present, data capture is only permitted if cloud coverage is above the height of the sensor and airborne platform. LIDAR shall not be conducted when the ground is covered by water (flood), snow, or ice. If a 1.5µm laser wavelength is used, special attention should be paid to ground surface wetness and humidity.

12.2 TIME OF DAY

Data acquisition operations may occur during either day or night. Unlike aerial photography, sun angle is not a factor in mission planning. However, time of day needs to be considered when imagery is acquired concurrently with the capture of LIDAR data to help assist in identifying features in post-processing production.

12.3 TIME OF YEAR

For obstruction detection, the Contractor shall fly in leaf-on conditions, as this increases the probability of detecting the tops of trees. For most geographic locations, data acquisition must be completed before late fall. The project instructions will contain specific recommendations and/or requirements.

13 POSITIONING AND ORIENTATION FOR THE DATA

13.1 POSITIONING

A. GPS DATA COLLECTION

1. All LIDAR data shall be georeferenced using integrated GPS/inertial systems employing dual frequency receivers.
2. All KGPS shall use at least two ground stations. The ground stations shall be accurately tied to the NSRS using Online Positioning User System (OPUS); shall be positioned to 0.1 meter accuracy, or better; shall be within or near the project area; and shall be within 100 kilometers of the entire project area. Additional ground GPS stations may be required, and CORS can be used as ground stations. The ground stations should be positioned on opposite sides of the operating area. The ground stations shall be positioned, or the flight path arranged, so that during flight operations the aircraft will, at least once, pass within 10 kilometers to each ground station.
3. The maximum GPS baseline shall not exceed 100 kilometers at any time during flight. Regardless of aircraft flight time, GPS ground station data shall be collected for four hours.
4. Ground station data shall be submitted to OPUS (http://www.ngs.noaa.gov/OPUS/) for positioning in the NSRS, even if the ground station is set up over a known survey monument in the NGS Database.

(See Section 20 for terminology related to ground GPS data collection.)

B. GPS SOLUTION PROCESSING

1. The Contractor shall collect, process, and submit the ground and airborne GPS data, both raw data and final processed data.
2. Differential KGPS solutions for the aircraft shall be obtained independently using each ground station.
3. These independent KGPS solutions shall be compared to display their differences in the north-south, east-west, and vertical components during the operational portions of the flights.
4. The RMS of these differences shall not exceed 5cm in the horizontal and 10cm in the vertical.
5. The KGPS solutions shall model the tropospheric delay using average surface meteorological values at the ground stations collected near the midpoint of operations. Supporting metadata shall be supplied to NGS.
6. The final KGPS solution will be an average of the separate ground station solutions.

C. ANTENNA

1. The GPS receivers should be equipped with antennas that have been approved by NGS. A choke-ring antenna to minimize multipath is preferred but not required.
2. The antenna height shall be accurately measured before and after the four-hour GPS session.

13.2 GROUND-BASED GPS RECEIVER

A. MARK – The ground-based receiver shall be set up over a known (or to-be-determined) marked ground station and shall run continuously during the mission. If a known ground station is used, it shall be in the NGS database and hence part of the NSRS. If a new ground station is used, it shall be marked permanently (to NGS specifications) or temporarily marked (such as a PK type nail or iron pin). It is recommended that an additional ground-based receiver be positioned on a PACS or SACS mark during the data collection if they are not being used as the primary ground stations already. This is so that other aeronautical and engineering surveys (which must reference PACS and SACS) may be able to use in the same reference system as the LIDAR data. This will preserve datum continuity in and around the airport across multiple surveys. (See section 21 for terminology related to GPS ground data collection.)

B. OBSERVATIONS – The position of an existing mark shall be checked by processing one GPS session and comparing the computed position with the NGS published position. A new mark shall be referenced to the NSRS by tying to one or more NGS CORS by static GPS methods. If the distance to the nearest NGS CORS is less than 50 miles, use at least two independent sessions, each 2 hours long. If the distance to the nearest NGS CORS is greater than 50 miles, use at least two sessions, each 4 hours long. **Make a separate tripod set-up and height measurement for each session.** Take care in the accurate recording of the height of the antenna both before and after the flight (i.e. before and after each GPS recording session). Record all heights, equipment serial numbers, etc. on the NGS forms: Visibility Obstruction Diagram and GPS Observation Log. For a listing of these and other forms on the NGS WWW site see: www.ngs.noaa.gov/PROJECTS/FBN/. Also, it is recommended that static observations be processed using the NGS "On-Line User Positioning Service" found at: www.ngs.noaa.gov/OPUS/index.html. Observations to establish a new, permanent mark shall be submitted in NGS "Blue Book" format.

C. RECOVERY – For an existing NSRS station, write a digital recovery note using the online Mark Recovery Form: http://www.ngs.noaa.gov/FORMS_PROCESSING-cgi- in/recvy_entry_www.prl. For a new, permanent station write a digital station description in NGS format using WDDPROC. For a new, temporary mark write a brief description adequate to recover the station. Take three photographs of the ground station to NGS specifications. (photographs of the CORS station are not required.)

For additional specification guidance on mark setting, GPS observations, data processing, and data submittal in NGS format, see FAA AC 150/5300-16A and the "General Specifications for Aeronautical Surveys, Volume I, Establishment of Geodetic Control on Airports" at:

- www.ngs.noaa.gov/AERO/Supinst.html
- www.ngs.noaa.gov/FGCS/BlueBook/
- www.ngs.noaa.gov/PROJECTS/FBN/

13.3 AIRCRAFT GPS RECEIVER

A. GPS OBSERVATIONS – The aircraft's GPS receiver shall be able to collect carrier phase observations and record, at least, once per second, from a minimum of four satellites (five or more preferred) at both the aircraft and the ground GPS receivers, for off-line processing. All data shall be collected with a PDOP of less than 3. After the post–processing, the GPS observation and ephemeris files are used to determine a flight path trajectory.

B. GPS LOCK – The aircraft shall maintain GPS satellite lock throughout the entire flight mission. If satellite lock is lost, on-the-fly ambiguity resolution methods may be used to recapture lock, while airborne. Report these instances, procedures used, and any other unusual occurrences. The GPS post-processing software may be capable of providing an output log of all incidents such as loss of GPS satellite lock. The formatted output log is acceptable as the report.

13.4 AIRBORNE ORIENTATION

An IMU shall be incorporated into the LIDAR unit. The IMU system shall be capable of determining the absolute orientation (roll, pitch, and yaw) at a minimum of 200 Hz and an absolute accuracy (RMSE) of 0.02 deg in roll and pitch and 0.08 deg in heading. Boresight calibration shall be performed so that the accurate orientation of each laser pulse can be determined. (See Section 8.2).

13.5 AIRBORNE POSITIONING AND ORIENTATION REPORT

The Report shall include at least the following paragraphs:

- – Introduction,
- – Positioning
  - – Data Collection
  - – Static Processing
  - – Kinematic Processing
  - – Data Sets
- – Orientation
  - – Data Collection
  - – Data Processing
  - – Data Sets
- – Final Results.

A. INTRODUCTION – Provide an overview of the project and the final processed data sets and list the data sets in table form with the following columns: Dataset ID, Date of Acquisition, Projects covered by the data set, and Description/Flight Line(s) Identification.

B. POSITIONING – Discuss the methodology, the hardware and software used (including models, serial numbers, and versions), the PACS, SACS, and/or CORS station(s) used, a general description of the data sets, flight lines, dates and times of sessions, the processing (including the type of solution–float, fixed, ion–free, etc.), and the results (discussion of the coordinates and accuracy). Submit a description of the data sets, and the raw and processed data. If the NGS OPUS website was used to process the static data, the Contractor shall provide a copy of the OPUS report. If a known station was used from the NGS database, the Contractor shall identify the station by name and permanent identifier, and provide the published coordinates used in the kinematic position step. If multiple ground stations were used, provide processing details, coordinates, and accuracy for all stations.

C. ORIENTATION – Discuss the factors listed above for Positioning.

D. FINAL RESULTS – Describe any unusual circumstances or rejected data, and comment on the quality of the data.

14 ANALYSIS WORKFLOW AND OUTLIER REMOVAL

14.1 ANALYSIS WORKFLOW

Generating final obstruction data from the LIDAR point cloud is a nontrivial task. For example, it is possible (even simple) to analyze the raw LIDAR point cloud against the OIS and extract only penetrating points. However, this is generally not a good idea, as it complicates the following tasks: 1) distinguishing between returns from real objects and those due to noise or clutter, 2) determining which points correspond to laser reflections from the same object, and 3) attributing detected obstructions. Based on research conducted by NGS, as well as valuable information obtained from private sector survey firms engaged in LIDAR airport survey, the generic workflow depicted graphically in Figure 14.1 is recommended. One critical aspect of this workflow is the placement of the object detection step before the OIS analysis step, so that the OIS analysis is performed on extracted objects (e.g., trees, buildings, antennas, poles, towers, etc.), rather than on the raw LIDAR points. Note: all detection algorithms and processes employed by the contractor shall be described thoroughly in a step-by-step approach in the appropriate sections of the final report.

The sequence of steps in this workflow has been ordered such that, irrespective of the specific detection algorithm used, the detection threshold can be set very low to minimize the probability of a miss (or, equivalently, maximize probability of detection). Object detection and collation are performed first, followed by the OIS analysis, then object-type attribution using the aerial imagery, and finally, verification and validation. False alarms (or "false objects") due to ground clutter or noise and randomly distributed throughout the project area will typically be automatically eliminated in the OIS analysis step, due to not penetrating or falling outside the OIS, and the remainder can be easily removed during the image analysis steps. This inherent tolerance of conservative detection thresholds in the object extraction process is an important aspect of the workflow, since the key consideration in airport obstruction surveying is to avoid missed obstructions that could potentially jeopardize flight safety. The imagery input is critical, as the imagery provides a complementary and independent data source. For a more in-depth discussion of the workflow benefits, refer to "Improved Approach to LIDAR Airport Obstruction Surveying Using Full-Waveform Data," *Journal of Surveying Engineering*, Vol. 135, No. 2, pp. 72-82, Parrish and Nowak, 2009. Also, a slight variation on the workflow entails introducing the aerial imagery at an earlier step to facilitate a primarily photogrammetric approach to obstruction detection, assisted by LIDAR (see Section 4.1).

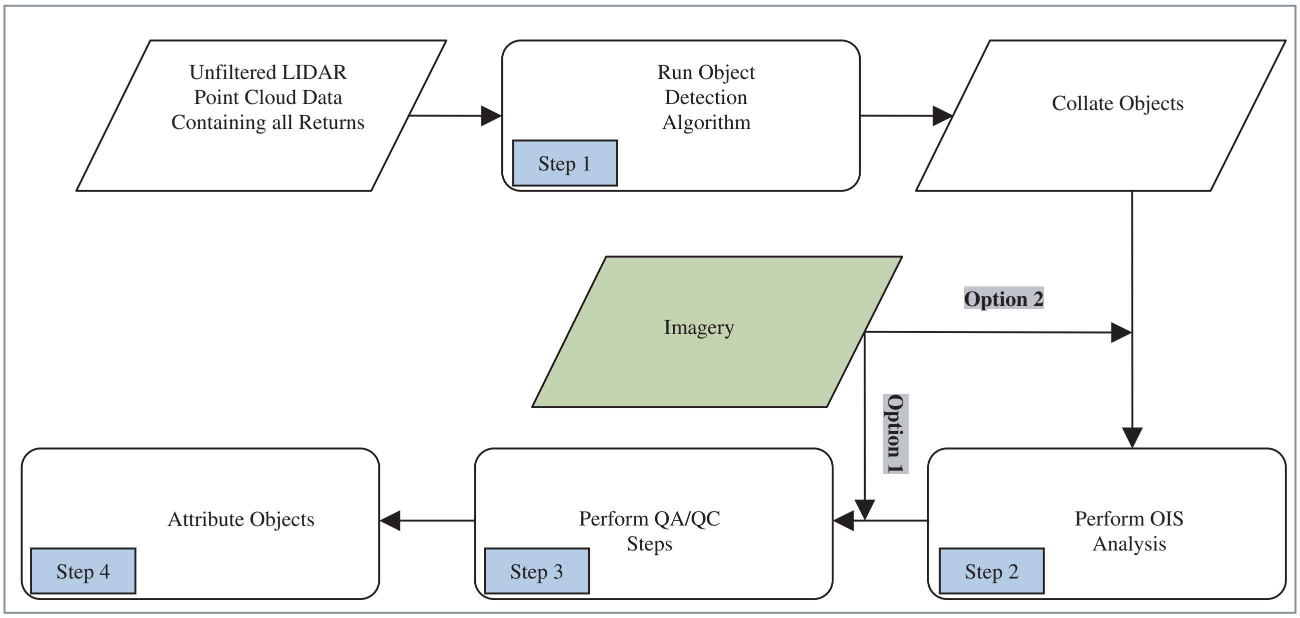

Figure 14.1 Basic workflow diagram for data processing

The OIS analysis (Step 2) shall be performed using NGS-supplied software contained in the NGS COM Surface Model Library (SML), a dynamic-link library that is compatible with Microsoft Visual Basic (VB), C++, and .NET. The library comprises dozens of functions that allow users to calculate surface penetrations, analyze features relative to specified OIS, and numerous other related tasks. NGS is responsible for updating SML as needed to reflect any changes in the definitions of the OIS (U.S. Dept. of Transportation, 2008). Each obstruction output from this workflow shall contain a latitude, longitude, NAVD 88 orthometric height, accuracy code (in accordance with *FAA Order 8260.19, Flight Procedures and Airspace*, U.S. Dept. of Transportation, 1993), and applicable zone information. Specific OIS requirements for each runway will be contained in the individual Project Instructions.

14.2 DATA CLEANING/FILTERING

The Contractor shall avoid pre-filtering of the data. One aspect of LIDAR collection and post-processing for airport obstruction surveys that it is very different than for other end-user application (e.g., floodplain mapping) pertains to cleaning/filtering of the data. Many production workflows that are geared towards bare-earth terrain modeling involve a great deal of filtering/cleaning of LIDAR points very far up the processing chain, or even during data acquisition. For example, some service providers will apply a range gate in the air that removes all objects less than a certain distance from the aircraft. Similar types of filtering (e.g., max elevation, min intensity, max range difference, etc., etc.) are often applied in post-processing. For airport obstruction surveying, this type of cleaning is very dangerous, as it can easily lead to removing points corresponding to reflections from obstructions, in some cases causing these obstructions to be missed. Therefore, the Contractor must deliver the raw LIDAR point cloud (with absolutely no points removed either in the air or in post-processing) as one of the deliverables. Additionally, the Contractor must be extremely careful about any cleaning or filtering done during the analysis workflow described above. In general, it is best to leave all points to be input to Step 1 from the LAS file and allow the Object Detection step to handle filtering. Any pre-cleaning/filtering performed should be explicitly described in the report. Additionally, these filtered points shall not be removed from the LAS file; instead they should be kept and attributed as "withheld" in the LAS file (classification bit encoding).

15 DATA LABELING

All Hard Disk Drives shall be labeled with the project name, collection date(s), Contractor name, and disk contents. LIDAR data Hard Disk Drives shall be able to be easily matched with the corresponding LIDAR flight log(s).

16 DATA SHIPMENT AND PROCESSING

16.1 SHIPMENT

The Contractor shall ship final deliverables in FAA/NGS format (on Hard Disk Drive), directly to FAA/NGS, to arrive within ten working days from the date of completion of the data processing. Copies of the LIDAR Flight Log and the raw navigation files may be made and used by the Contractor to produce and check the final deliverables.

16.2 FAA/NGS NOTIFICATION

The same day as shipping, the Contractor shall notify FAA/NGS of the data shipment's contents and date of shipment by transmitting to FAA/NGS a paper or digital copy of the data transmittal letter via email or fax.

17 DELIVERABLES

The following list outlines the required deliverables resulting from Airport OIS Survey work. Additional or custom deliverables may be described in individual project instructions. The Contractor is also responsible for providing all required deliverables in FAA AC 150/5300-16A, FAA AC 150/5300-17B, and FAA AC 150/5300-18B. If the Contractor finds a contradiction or redundancy, then FAA/NGS shall be notified.

A. LABOR, EQUIPMENT AND SUPPLIES – The Contractor shall provide logs of all labor, equipment maintenance and calibration (including aircraft and LIDAR system), supplies, and material to produce and deliver products as required under this document. Full information on a LIDAR vendor shall be provided if used as a specialized subcontractor by the SC.

B. LIDAR SURVEY AND QUALITY CONTROL PLAN – Prior to data acquisition, submit a proposed LIDAR Survey and Quality Control Plan which specifies the data collection parameters to be used and contain a map of the flight lines and the project coverage area, including flying height, speed over ground, scan angle, PRF, overall point density, and horizontal and vertical point spacing. FAA/NGS will review the proposed mission planning reports, normally within five business days, and will respond in writing with approval and/or comments. The Final Report shall contain map(s) showing the flight lines and boundaries of LIDAR data actually collected.

C. GPS SURVEY LOCATION OF TEST APPARATUS DESCRIBED IN SECTION 8.3.3.

D. LIDAR RAW DATA – Submit the completed data collection raw output.

E. LIDAR PRODUCTS – Required products may include: LIDAR point cloud files, intensity images, attributed objects/obstructions, and other products described in AC 150/5300-17B and AC 150/5300-18B. The project instructions will specify which additional products, if any, are required. (See Section 3.1 D.)

F. IMAGERY - All imagery including orthophotos (if required in SOW and/or project instructions) shall be delivered according to the format and requirements outlined in FAA AC 150/5300-17B, specifically Sections 19-22 inclusive.

G. FLIGHT REPORTS – Submit the completed, original LIDAR Flight Logs with the data, and a copy directly to FAA/NGS.

H. GPS/ IMU FILES – The Contractor shall submit the original, raw data files and processed trajectory files directly to FAA/NGS, to arrive at FAA/NGS along with the raw data points and final products. The raw data files shall include RINEX files generated from each receiver's proprietary data files. (See sections 12.1 and 12.4.)

I. AIRBORNE POSITIONING AND ORIENTATION REPORT – Submit raw GPS and IMU data (in the manufacturer's format) along with the final processed GPS trajectory and post-processed IMU data. Also submit a report covering the positioning and orientation of the LIDAR. (See Section 11.5.)

J. RANGE AND SCANNER ANGLE FILES – The Contractor shall submit the original, raw data files directly to NGS, to arrive at NGS along with the raw data points and final products.

K. GPS CHECK POINTS – Submit an organized list of all GPS points used for the project as ground stations and accuracy check points. Indicate which GPS points are pre-existing ground control and which stations are new and positioned relative to the NSRS. See project instructions and Sections 3.1 C and 12.2.

L. FAA/NGS SURVEY FORMS – The Contractor shall prepare and submit the following FAA/NGS forms for each GPS check point and the GPS ground station(s): Visibility Obstruction Diagram, GPS Observation Log, Recovery Note or Station Description. (See Section 12.2.)

M. CALIBRATION REPORTS – There is no standard format for the calibration reports. However, the calibration reports shall contain, at a minimum, the following information:
- The date the calibration was performed.
- The name of the person, company, or organization responsible for performing the calibration.
- The methods used to perform the calibration.
- The final calibration parameters or corrections determined through the calibration procedures.

N. SENSOR MAINTENANCE – Provide maintenance history directly to FAA/NGS of the sensor to be used for acquiring LIDAR. (See Section 4.1.)

O. DATA SHIPMENT – See Sections 3 and 15 for instructions.

P. DATA SHIPMENT REPORTING – The Contractor shall notify FAA/NGS of each data shipment's contents and date of shipment by transmitting to FAA/NGS a paper or digital copy of the LIDAR Flight Log (marked "copy" at the top) and a copy of the data transmittal letter via email or facsimile. This shall be done the same day the data is shipped to the data processing contractor. (See Section 15.)

Q. UNUSUAL CIRCUMSTANCES – The Contractor shall also notify FAA/NGS of any unusual circumstances that occur during the performance of this project which might affect the deliverables or their quality and especially of any deviation from this project. This may be included in the weekly email required below, unless urgent.

R. DEVIATIONS FROM SOW – Requests to exceed or deviate from the project instructions will be considered if written justification is provided to FAA/NGS in advance. No deviation is permitted until written approval is received from FAA/NGS.

S. STATUS REPORTS – The Contractor shall submit project status reports via email to the Contract Officer's Technical Representative (COTR) contacts in Section 14 every week, until the work is complete. **These reports are due at NGS by 2:00 p.m. EST each Monday.** These reports shall include a summary of completed data acquisition, with dates completed; data shipped, and dates; and any unusual circumstances, equipment malfunctions, and/or any disturbance of the sensor. **A weekly status report is required even if no progress has been made.**

T. FINAL REPORT

The Contractor shall supply to FAA/NGS a Final Report incorporating all of the information in this Deliverables section including, at least, the sections listed below:

1. Work performed under this contract, discuss each deliverable including: the maximum range from the ground station, the minimum swath overlap, percent of good laser returns (if available), standard deviation and residuals in GPS trajectories, and an explanation of the HARD DISK labeling;
2. Equipment used to perform this work, including hardware models and serial numbers, calibration reports, and software names and versions (include aircraft and LIDAR info);
3. Flight line map(s), and project coverage area;
4. Discussion of data quality including QA/QC procedures;
5. Ground Control Report, including a station list in table format;
6. Aircraft Navigation;
7 Airborne kinematic GPS Report, including ground stations;
8. Weather, solar altitude, and time of year;
10. Any unusual circumstances or problems, including equipment malfunctions (including those already reported);
11. Any deviations from this SOW, including those already reported;
12. Any recommendations for changes in the SOW for future work.

U. PROPERTY OF DATA – All original data, from the instant of acquisition, and other deliverables required through this contract including raw data and final products, are and shall remain the property of the United States Government. This includes data collection outside the project area. See specific guidelines and/or deviations in project instructions.

V. OPTIONAL DELIVERABLE – Georeferenced raster photo/imagery draped over a LIDAR-derived surface model and obstruction points to the Airport Sponsor, FAA, and NGS.

18 REVIEW

Data and other deliverables not meeting these specifications may be rejected.

19 REFERENCES

ASPRS, 2004. ASPRS LIDAR Guidelines – Vertical Accuracy Reporting for LIDAR Data V1.0. American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland.

Flood, M. *Eye Safety Concerns in Airborne LIDAR Mapping*. Proceedings of the ASPRS 2001 Annual Convention, 23-27 April, St. Louis, Missouri (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland), un-paginated CD-ROM, 2001.

Parrish, C.E., and R.D. Nowak, 2009. Improved Approach to LIDAR Airport Obstruction Surveying Using Full-Waveform Data. *Journal of Surveying Engineering*, Vol. 135, No. 2, pp. 72-82.

Parrish, C.E., G.H. Tuell, W.E. Carter, and R.L. Shrestha, 2005. Configuring an airborne laser scanner for detecting airport obstructions. *Photogrammetric Engineering & Remote Sensing*, Vol. 71, No. 1.

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U.S. Department of Transportation, 1993. *FAA Order 8260.19, Flight Procedures and Airspace*. Federal Aviation Administration, Washington, DC.

U.S. Department of Transportation, 1996. *FAA No. 405, Standards for Aeronautical Surveys and Related Products, Fourth Edition*. Federal Aviation Administration, Washington, DC.

U.S. Department of Transportation, 2007. *FAA AC 150/5300-16A*, *General Guidance and Specifications for Aeronautical Survey Airport Imagery Acquisition and Submission to the National Geodetic Survey*. Federal Aviation Administration, Washington, DC. September 15, 2007.

U.S. Department of Transportation, 2008. *FAA AC 150/5300-17B*, *General Guidance and Specifications for Aeronautical Survey Airport Imagery Acquisition and Submission to the National Geodetic Survey*. Federal Aviation Administration, Washington, DC. September 29, 2008.

U.S. Department of Transportation, 2009. AC 150/5300-18B, *General Guidance and Specifications for Submission of Aeronautical Surveys to NGS: Field Data Collection and Geographic Information System (GIS) Standards.* Federal Aviation Administration, Washington, DC. May 21, 2009.

20 TERMINOLOGY AND DEFINITION RELATED TO GROUND-BASED GPS DATA

Ground-based GPS data are collected for both aerial imagery and LIDAR remote sensing projects for a variety of purposes, which, in any given project, can include any or all of the following: 1) post-processing of airborne GPS trajectories, 2) geometric sensor calibration, 3) georeferencing of remotely-sensed data, and 4) spatial accuracy assessments. For purposes of this report, the following terms and definitions related to ground-based GPS data collection are adopted:

20.1 GPS Base Station

A GPS base station consists of a GPS antenna and receiver set up over a fixed location with accurately known coordinates. For directly-georeferenced airborne remote sensing projects (e.g., acquisition of LIDAR or directly-georeferenced aerial imagery), the GPS base station data are used in post-processing the airborne kinematic GPS data. Typically, NGS recommends a dedicated base station in or near the project site, although Continuously Operating Reference Stations — CORS [*see definition below*] can, in some circumstances, be used in place of dedicated (i.e., project-specific) base stations.

In the past, base stations were almost always set up over a survey monument (e.g., PACS, SACS, or other geodetic control point). However, NGS' Online Positioning User Service (OPUS) is increasingly being used to obtain base station coordinates, so that the base station can be set up in any safe location in or near the project site with a clear view of the sky. One issue for airport applications is that, in the western United States for airports with PACS and SACS that were included in the 2007 adjustment, an OPUS solution for an unknown ground station will not agree with the PACS, since the OPUS reference system is NAD 83 (CORS) and the PACS reference system is NAD 83 (2007). If OPUS is used in the western U.S., then HTDP [*see definition below*] should be used to predict the amount of change for the unknown point from NAD 83 (CORS) to NAD 83 (2007). To avoid this complication, and for other reasons explained below [*see control station definition*], the recommended procedure is to set up the GPS base station over the PACS or SACS for LIDAR airport surveys.

Note: in many surveying applications, GPS base stations are equipped to actively broadcast differential GPS corrections to other GPS receivers either via radio modem or cellular connection to the internet. However, in airborne remote sensing for mapping applications, it is more common to post-process the airborne kinematic GPS data, rather than relying on real-time corrections broadcast from the base station. For airport LIDAR projects, the airborne GPS trajectories must be post-processed.

20.2 Ground Control Point (GCP)

For purposes of this report, this term is used rather broadly to refer to an accurately-surveyed (usually with GPS), identifiable point on the ground that can be used for: (a) geometric sensor calibration, (b) georeferencing, or (c) spatial accuracy assessments. It is typically required—especially for controlling aerial imagery—that the GCPs be readily identifiable in the remotely-sensed data. For example, common GCPs for aerial imagery acquisition include sidewalk corners and paint stripes (especially, where paint stripes intersect, as in a parking lot or tennis court), the image coordinates of which can be precisely measured. Where there are no readily-identifiable features in the scene, pre-marked "panels" or "targets" can be placed in the project site and surveyed with GPS in advance of the airborne data acquisition. If these features are also identifiable in the LIDAR intensity data and have accurately-surveyed heights, in addition to horizontal coordinates, then they can simultaneously serve as GCPs for 3D imagery and LIDAR.

20.3 Control Station

Control stations are permanent survey marks with precisely determined latitudes, longitudes and elevations relative to a geodetic datum. PACS and SACS are control stations established in the vicinity of an airport and tied directly to the National Spatial Reference System — NSRS. Based on FAA guidance documents, all aeronautical and airport engineering surveys should be referenced to the PACS and/or SACS. Over time, an airport operator will likely find that survey data collected from projects that are directly tied to the PACS and/or SACS will be much easier to relate to other survey data from other airport projects that are also tied to the PACS and/or SACS. Problems will arise when one project was tied to a CORS that has since been decommissioned, or a HARN that was destroyed by a construction project. If all projects are related to the PACS and/or SACS and those control stations were established in locations at the airport that are very unlikely to be destroyed or disturbed, then all survey projects will be able to be related to each other for a very long time. Setting up GPS base stations used for LIDAR and aerial imagery acquisition over PACS or SACS, and tying airport GCPs to the PACS and SACS, therefore ensures datum consistency for airport-specific applications.

20.4 Check Point

Check points are GCPs specifically intended or used for assessing the spatial accuracy of the data. In order to ensure an <u>independent</u> accuracy assessment, check points should be maintained separate from other GCPs and excluded from sensor calibration and georeferencing procedures.

20.5 HTDP

NGS' HTDP (Horizontal Time-Dependent Positioning) software enables users to predict horizontal displacements and/or horizontal velocities related to crustal motion in the United States and its territories. The software also enables users to update positional coordinates and/or geodetic observations to a user-specified date. HTDP supports these activities for coordinates in NAD 83, as well as in all official realizations of the International Terrestrial Reference System (ITRS), and all official realizations of the World Geodetic System of 1984 (WGS 84). Accordingly, HTDP may be used to transform positional coordinates between any pair of these reference frames in a manner that rigorously addresses differences in the definitions of their respective velocity fields. HTDP may also be used to transform velocities between any pair of these reference frames. [Source: National Geodetic Survey, 2008. HTDP User's Guide: http://www.ngs.noaa.gov/TOOLS/Htdp/htdpUserGuide.pdf]

20.6 CORS

Continuously Operating Reference Stations (CORS) provide Global Navigation Satellite System (GNSS - GPS and GLONASS) carrier phase and code range measurements in support of three-dimensional positioning activities. NGS manages a network of CORS with data available for download via the internet: http://www.ngs.noaa.gov/CORS/. Each CORS station comprises a permanent GPS site. By using CORS as base stations [*see definition above*], surveyors can eliminate the need to set up their own GPS equipment at the base site, while simultaneously ensuring that their data is tied to the National Spatial Reference System (NSRS). However, as described above, for airport LIDAR surveys, it is recommended that one dedicated base station be set up over the PACS or SACS, rather than relying solely on CORS.

21 ACRONYMS

AC	Advisory Circular
AGL	Above Ground Level
ANSI	American National Standards Institute
ASP	Aeronautical Survey Program (National Geodetic Survey)
ASPRS	American Society of Photogrammetry and Remote Sensing
COTR	Contract Officer's Technical Representative
CORS	Continuously Operating Reference Stations
FAA	Federal Aviation Administration
FOV	Field of View
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
HPS	Horizontal Point Spacing
HTDP	Horizontal Time-Dependent Positioning
IMU	Inertial Measurement Unit
KGPS	Kinematic Global Positioning System
LAS	Laser Data Format
LIDAR	Light Detection and Ranging
LRCC	LIDAR Radiometric Calibration Center
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NSRS	National Spatial Reference System
NTFS	New Technology File System (for Windows NT Operating System)
OIS	Obstruction Identification Surface
OPUS	Online Positioning User System
PACS	Primary Airport Control Station
PDOP	Position Dilution of Precision
POS	Position Orientation System
PRF	Pulse Repetition Frequency
RGB	Red Green Blue
RMSE	Root Mean Squared Error
SC	Survey Acquisition Contractor or Survey Contractor
SACS	Secondary Airport Control Station
SML	Surface Model Library
SOW	Statement of Work or Scope of work
UTC	Coordinated Universal Time — formerly known as Greenwich mean time (GMT)
VOs	Vertical Objects
VPS	Vertical Point Spacing

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